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14. ABSTRACT

The goal of the Community Sediment Transport Modeling System (CSTMS) was to produce an open-source model that couples hydrodynamics (circulation and waves), sediment transport, and morphodynamics. The model is intended to be used as both a research tool and for practical applications. An accurate and useful model requires coupling sediment-transport with hydrodynamic forcing and stratigraphic evolution. Ultimately, the modeling system will consist of interoperable modules, conforming to a community-accepted standard such as the Earth System Modeling Framework (ESMF).

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LONG-TERM GOALS

The goal of the Community Sediment Transport Modeling System (CSTMS) was to produce an open-source model that couples hydrodynamics (circulation and waves), sediment transport, and morphodynamics. The model is intended to be used as both a research tool and for practical applications. An accurate and useful model requires coupling sediment-transport with hydrodynamic forcing and stratigraphic evolution. Ultimately, the modeling system will consist of interoperable modules, conforming to a community-accepted standard such as the Earth System Modeling Framework (ESMF).

OBJECTIVES

The specific objectives of the project included:
- developing sediment-transport modules, testing them as stand-alone modules, and incorporating them into the Regional Ocean Modeling System (ROMS) and stand-alone models;
- incorporating hydrodynamic processes into ROMS that are essential for quantitative sediment-transport modeling;
- developing ESMF-compatible model coupling of components of CSTMS modules;
- developing and distributing tools for model development and testing;
- documenting the sediment transport algorithms and maintaining a collaborative site for distribution, documentation, tutorials, algorithms and user-support software, test problems, analysis tools, discussion forum, and outreach;
- applying CSTMS to specific field environments.

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APPROACH

The team included a large group of sediment-transport specialists, hydrodynamicists, and numerical modelers (Table 1). The team communicated via annual meetings, on-line meetings, and sub-group interactions. The core of the project involved design and implementation of the modular model framework, development of standards and conventions for data exchange and tools for pre- and post-processing and analysis, and development of modules from new sediment-transport algorithms. A collaborative web site hosting code, test cases, documentation, and discussions was established early in the project and continually updated by program participants (https://www.myroms.org/projects/cstm). Finally, use of the model in real-world applications was conducted by the Partner Investigators and others.

Table 1: The CSTMS Team

Organization	Personnel	Oversight and management	Module development	Software tools	Algorithm development	Community engagement	Model application
Woods Hole Oceanographic Institution	R. Geyer J. Trowbridge P. Traykovski	X			X		X
U.S. Geological Survey Coastal and Marine Geology Program	C. Sherwood R. Signell J. Warner B. Butman	X	X	X	X	X	X
Naval Research Lab (Stennis)	T. Keen T. Campbell	X	X		X		X
U.S. Army Corps of Engineers (ERDC)	D. Resio J. Hanson	X	X	X	X		X
HR Wallingford	R. Soulsby R. Whitehouse	X	X		X		X
Mississippi State University	S. Bhate	X		X		X	
Ohio State University (Univ. of New Hampshire)	D. Foster J. Fredsoe	X			X		X
Oregon State University	E. Skyllingstad N. Perlin		X				
Univ. Miami RSMAS	Y. Chang				X		
Rutgers University	H. Arango D. Robertson	X	X			X	
Stevens Institute	A. Blumberg	X			X		
UNESCO-IHE	D. Roelvink	X					X
University of California, Los Angeles	J. McWilliams Y. Uchiyama	X	X		X		X
University of Delaware	J. Kirby F. Shi T. Hsu	X	X		X X		
University of Maryland	L. Sanford				X		X
WL|Delft Hydraulics Laboratory	B. Jagers J. Winterwerp	X					

RESULTS

Model Source Code

The essential product of this project is the source code of a functional and useful sediment-transport model. CSTMS routines for sediment transport are distributed with the Regional Ocean Modeling System (ROMS). The code is freely available to all registered ROMS users via the ROMS website (http://www.ocean-modeling.org/). The sediment-transport routines developed by Blaas et al. (2007) at UCLA and by Warner et al. (2008c) at the USGS were initially released as a CSTMS product in October 2006 with ROMS 2.1. Since then, enhanced and improved code has been released via the ROMS repository. A second CSTMS code repository contains a duplicate of this trunk code and several branches maintained by individual investigators. Some of the experimental code that has not yet been incorporated in the trunk is available to the public in these development branches.

The CSTMS code is copyright the ROMS/TOMS with an open-source license modeled after the MIT-X license. This license ensures that ROMS and CSTMS source code remains available to the public, but does not restrict development or adaptation of the software.

In addition to ROMS routines, the CSTMS project has introduced other source code into the public domain. This includes the 3D model DUNE, an optical model, a Java toolbox, and wave-current interaction code in the UCLA version of ROMS. The DUNE model was developed by Fredsoe and others and used during CSTMS by Foster and students. The optical model, developed at NRL Stennis for post-processing the output of suspended-sediment models, was contributed by Stavn and Keen (2004; Keen and Stavn, 2000). Both of these models are publically available on a repository maintained by the USGS. The Java toolbox, discussed in more detail below, is available on SourceForge.

Technical Enhancements to ROMS

A robust version of ROMS that includes circulation, waves, sediment transport, and morphology is on line and available to the public. New versions of ROMS (version 3.2) are under continuous development.

Model Coupling

The main version of the code includes multi-model coupling of ROMS, SWAN, and the CSTMS sediment-transport routines using the Model-Coupling Toolkit (MCT; Warner, Perlin, and Skyllingstad, 2008b). An Earth System Modeling Framework (ESMF) driver was developed by Perlin and Arango to couple ROMS to other models, and the code for this is on a development branch in the CSTMS repository. This driver uses the ESMF superstructure to control the flow of data between all models and enables volumetric coupling inside the ROMS computational kernel without the need to split the code into different routines to meet superstructure requirements.

Composite Grids

Structured-grids, such as those used by ROMS, often are not optimal for complicated coastal regions, because they often do not fit the coastline closely and cannot efficiently distribute computational points. Warner, Geyer, and Arango (in press) developed a method that allows an unlimited number of

individual grids to be combined efficiently to produce a composite grid. They implemented this new method in ROMS, tested it with a simple case (the "dogbone" case, discussed in the 2008 annual report) and used it in an application for the Hudson River estuary, in which an accurate representation of the connection between different segments of the domain was an essential requirement of the science. For this illustrative case they investigated salt transport and the residence time of a passive tracer. This application illustrates the utility of the grid connectivity method for circulation and dispersion studies in regions of complex geometry. The same domain is now being used to address the sediment transport processes in this estuarine regime, where again the connections between segments are critically important to the scientific questions.
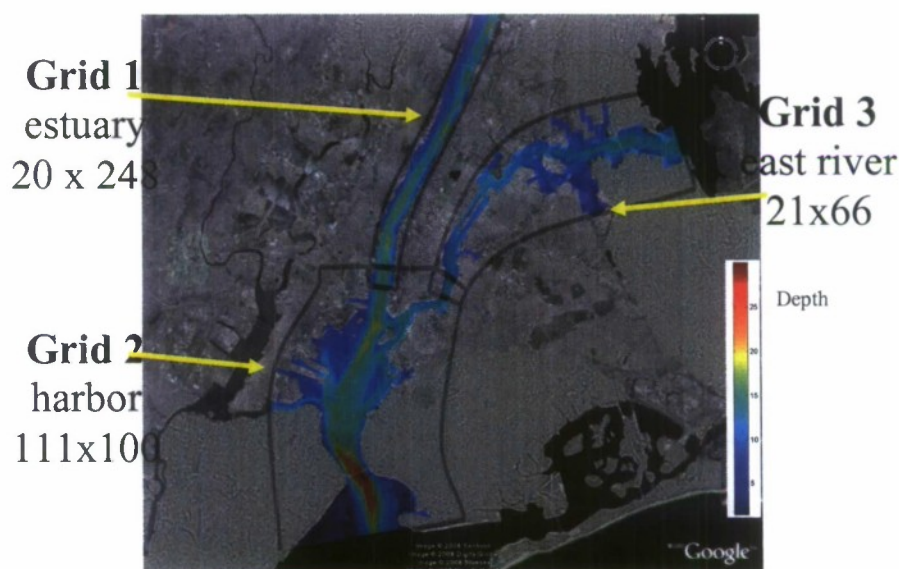

Figure 1. The Hudson River – New York Harbor domain as implemented using the composite grid algorithm in ROMS 3.2. Composite grids provide an efficient means of simulating transport processes in environments with complicated geography.

Model Output Infrastructure

A long-term goal of CSTMS is to eventually support a variety of wave, current and met models in addition to ROMS, SWAN, and WRF. Toward that end, Signell and Bhate have developed a procedure and a set of tools for distributing and accessing data from different models with a standards-based approach. The procedure is designed to be simple for model data providers. They standardized using the Climate and Forecast (CF) conventions, but instead of forcing providers to rewrite their output files, the output files are standardized at a central server via NcML, an XML markup language which can repair or add metadata to meet the CF conventions. The data are then available through a THREDDS Data Server via OpenDAP. OpenDAP with CF Conventions is the only existing web service that is capable of serving the model output from the types of native grids commonly used for coastal models (e.g. curvilinear horizontal coordinates, sigma or s-coordinate systems) in a standardized form. They are building an object oriented toolkit for Matlab that reads CF-compliant data from OpenDAP, and have demonstrated that they can read 3D georeferenced data from POM, ROMS, SWAN, WRF, ECOM and WaveWatch 3 all with the identical model-independent Matlab command. Using this approach, the CSTMS model results can also be accessed by software developed wholly outside of CSTMS, like the Unidata's Integrated Data Viewer, or the Reading E-Science Centre

ncWMS server/GODIVA2 client. This standards-based approach has applications well beyond CSTMS and is likely to be adopted by the NOAA IOOS Data Integration Framework for harmonizing access to model output from the National Backbone and from the Regional Associations.

Scientific Advances in CSTMS

The CSTMS project supported scientific advances in hydrodynamics and sediment-transport. Some of these have been successfully implemented in the publically available model code; other advances have only been implemented in development branches or are suitable for establishing model parameterizations.

Wave-Current Interactions

Two different wave-current interaction formulations were developed as part of CSTMS. The Mellor (2005) formulation was implemented by Warner (Warner et al., 2008b, c). Testing of this formulation against observations at the Martha's Vineyard Coastal Observatory and the Sandy Duck experiment yielded excellent agreement in the wave-induced transport (Figure 2), providing support for this approach. This approach has been compared with the quasi-3D approach used in NearCOMM by Haas and Warner (2009).
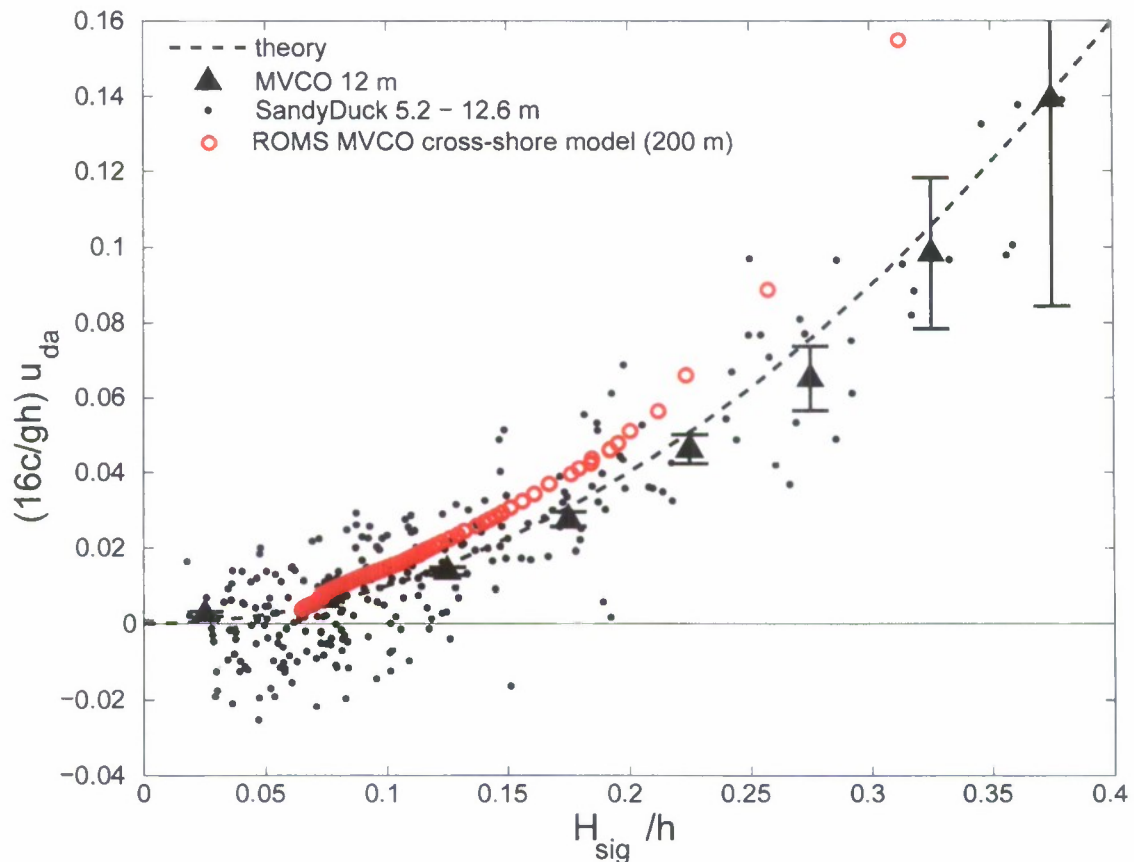

Figure 2. Results of the wave-current interaction formulation of Mellor (2005) as implemented by Warner et al (2008 b, c) compared with Stokes theory and observations of Lentz et al. (2008). The x-axis is the significant wave height normalized by the water depth, and the y-axis is the observed and modeled wave-momentum flux (normalized by the local wave propagation speed).

The UCLA group also addressed wave-current interaction, using the vortex-force formalism by McWilliams et al. (2004) extended for application to strong currents and wave-breaking applicable to wave-driven nearshore currents within and near surf zones. A set of WKB wave ray and action conservation equations, a roller energy conservation equation (Svendsen, 1984) that describes breaking-wave-driven inshore-traveling bore, referred to as a surface roller, and current and tracer equations with wave-current interaction has been implemented in ROMS with appending non-conservative parameterization to account for wave energy loss due to depth-induced wave breaking proposed by Thornton and Guza (1983). The KPP vertical eddy viscosity/diffusivity submodel (Large et al., 1984) in ROMS has also been modified to incorporate effects of breaking waves. An investigation of littoral currents driven by incident gravity waves in depth-averaged configurations on a single barred beach topographies relevant to a natural sandy beach at Duck, NC, has been carried out (Uchiyama et al., 2009). Roles played by wave-current interaction are investigated for so-called shear waves i.e., low-frequency fluctuating motions associated with nearshore shear instability in alongshore currents (Figure 3). A full three-dimensional wave-current interaction model has also been developed and is being extensively tested with a surf-zone scale Duck-type configuration and with an inner-shelf-scale, rotating and stratified configuration to be tested with measurements near Martha's Vineyard.
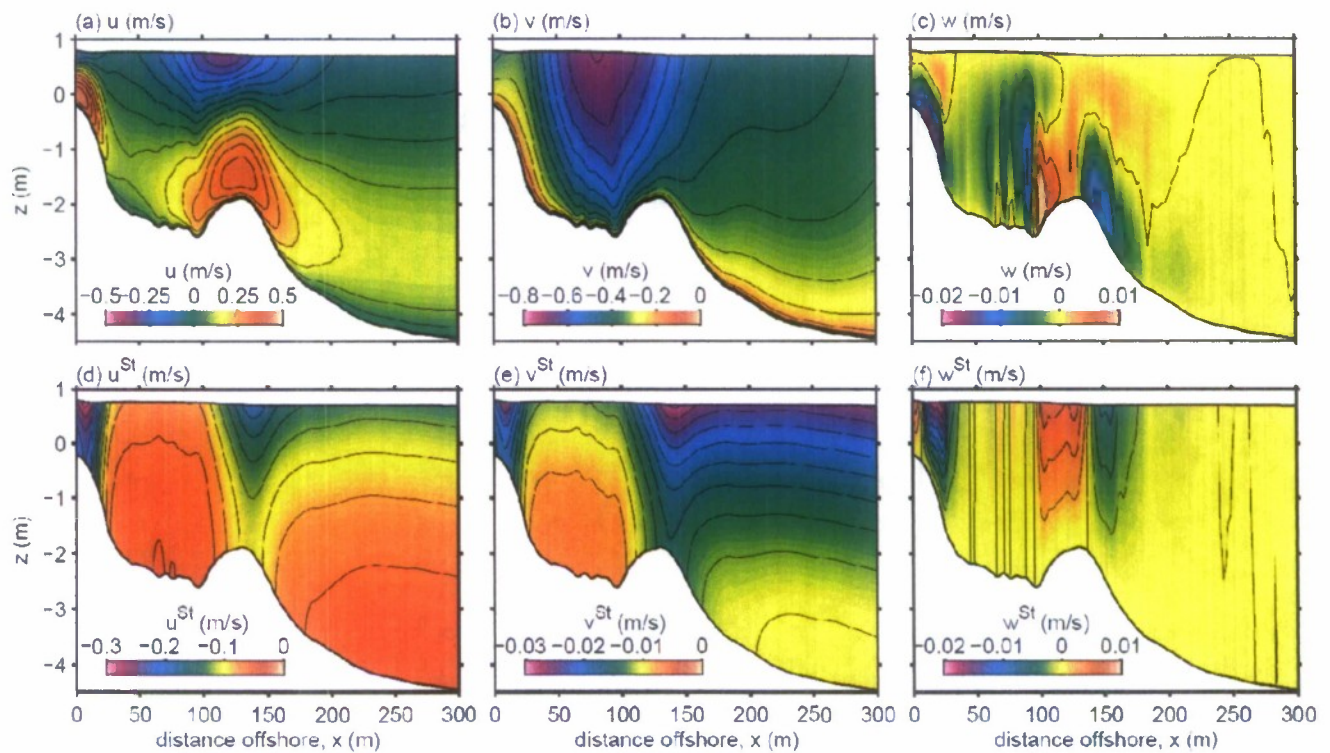

Figure 3. Examples of wave-driven flow field and Stokes drift velocities simulated in the new three-dimensional wave-current interaction model during DUCK94 experiment. (a) cross-shore velocity u, (b) alongshore velocity v, (c) vertical velocity w, (d) cross-shore Stokes velocity u^{St}, (e) alongshore Stokes velocity v^{St}, and (f) vertical Stokes velocity w^{St}. Contour intervals are (a) 0.05 m/s, (b) 0.05 m/s, (c) 0.004 m/s, (d) 0.02 m/s, (e) 0.002 m/s and (f) 0.002 m/s. Incident wave is specified with an amplitude of 0.8 m and a period of 6 s at an angle of 13 degree off the shore-normal direction (Uchiyama et al., 2009).

Shoreline Boundary Conditions

Kirby,Shi, and Zhu have implemented in SHORECIRC an algorithm for new shoreline boundary conditions with surf-swash interaction. This addresses a common problem that exists in ROMS and virtually all other models: in a wave-averaged model that neglect swash-zone dynamics, the shoreline boundary is specified at the location where the mean total water depth is zero, which may not be consistent with the actual wave-averaged properties at the swash zone and cannot account for transport of water and sediment above this elevation. Kirby and Shi have redefined the shoreline boundary at the wave run-down position estimated from the residual bore height according to Brocchini and Bellotti (2002). They re-derived the Lagrangian-type wave-averaged equations with shoreline boundary conditions that are consistent with Brocchini and Bellotti's swashzone integrated model. The surf-swash interaction is presented by the mass and momentum exchanges between the surf zone and swash zone at the newly defined shoreline boundary (Figure 4; Zhu, Shi, and Kirby, in preparation).
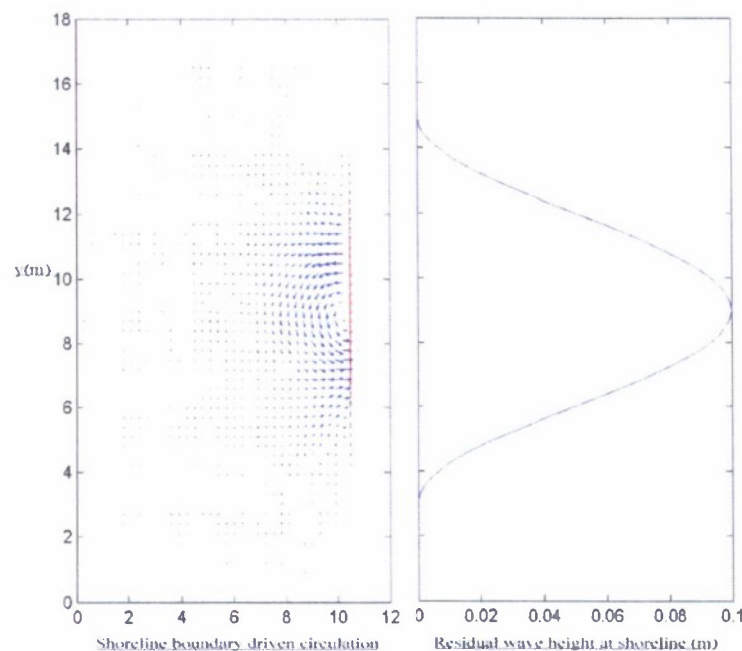

Figure 4. An idealized residual wave height distribution in the longshore direction with 30 degrees of incident wave angle from SE (right). Circulation driven by the swash zone mass and momentum fluxes at the surfzone-swashzone interface (left). The red arrows represent alongshore flux integrated over the swashzone.

They implemented the wave breaking formula of Baldock and Holmes (1999, corrected by Janssen and Battjes, 2008) in the REF/DIF wave model in order to predict unsaturated breaking waves. The residual wave height at the newly defined shoreline is used to evaluate the swashzone wave runup height as well as the integral hydrodynamic properties in the swash zone. They have carried out numerical experiments on nearshore circulations enforced by swash zone dynamics the results are included in Zhu et al. (2009).

Roelvink et al. (2009) investigated shoreline processes through continued development XBeach, a two-dimensional depth-averaged wave and circulation model for sediment-transport in the nearshore zone that resolves infragravity wave motions and simulates dune erosion, overwash, and breach formation. Key advances include coupling with Delft3D, successful prototype simulation of a barrier-beach breach (Figure 5) and incorporation of groundwater interaction with swash. Roelvink transferred and explained XBeach wave action balance code to Warner and USGS post-doc Maitane Olabarrieta for implementation in ROMS. Kirby and Shi have combined ROMS and Xbeach results to model overwash at Santa Rosa Island (Florida) during Hurricane Katrina.
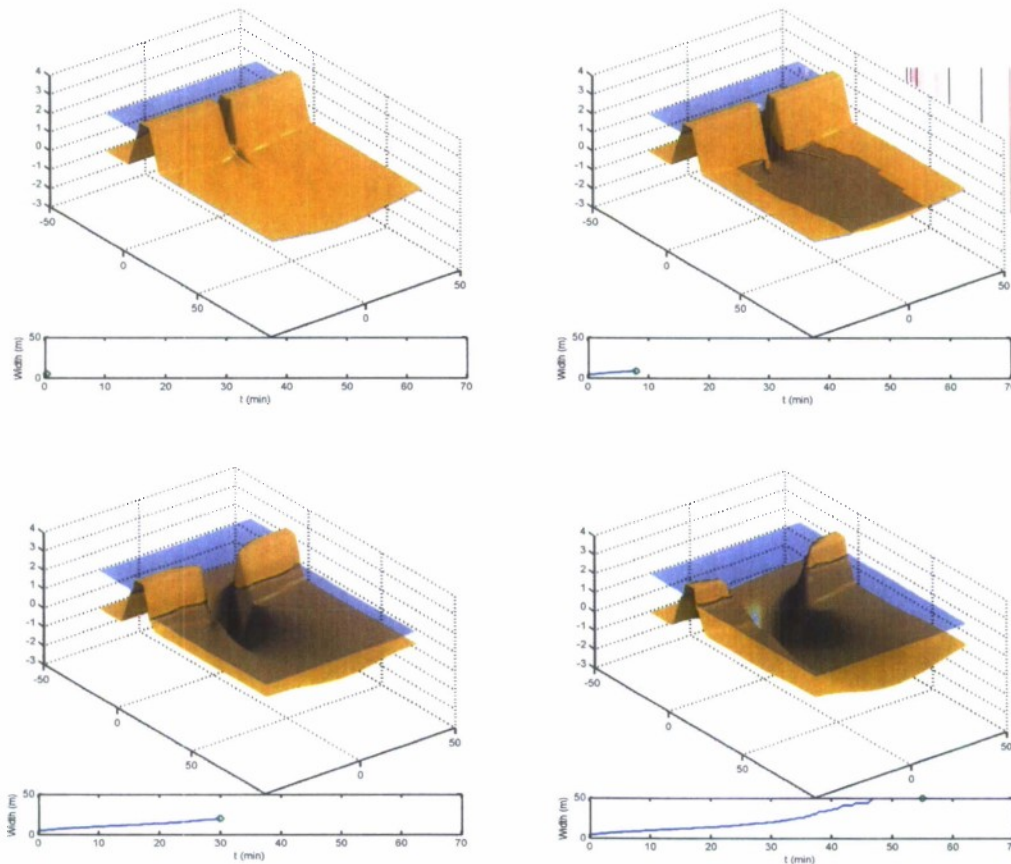

Figure 5. XBeach simulation of enlargement of a dune breach and evolution of the breach into a tidal channel.

ECOMSEDZLJ

Developments in the ECOMSED model (HydroQual, Inc., 2001) complement and inform developments in ROMS through comparison. ECOMSED developers Alan Blumberg and Liang Kuang participated in the CSTMS project with the objective of providing a comparison sediment transport model. The comparison model will provide a means for assessing the predictive skill of ROMS. Model performance will be evaluated by appealing to a series of illustrative test cases of increasing complexity designed to isolate specific sediment processes. A new sediment transport model ECOMSEDZLJ with new sediment dynamics is being developed, in which a buffer layer is added to decrease excessive sediment erosion during tides (Jones and Lick, 2001; Zeigler, 2008; Quantitative Environmental Analysis, Inc., 2008). The new model is being tested and will be

ultimately used in the Hudson River for understanding the characteristics of the sediment transport. An idealized river with geometry similar to the Hudson was constructed to understand the secondary flow in high curved river parts and will serve as a basis for coupling ECOMSEDZLJ with the high resolution forecast model of the waters of New York and New Jersey called NYHOPS (Bruno et al, 2006).

Parameterization of Wave-Current Boundary Layer Processes in ROMS using Dune

Foster, Fredsoe, and students have been using Dune to model wave-current bottom boundary layers with the goal of developing sub-grid scale parameterizations suitable for use in CSTMS. Dune is a quasi-three dimensional model that resolves flow and sediment transport over rough beds. The quasi-three dimensional version of the Dune code has been modified to allow forcing for combinations of waves and mean flow at arbitrary angles. The current code is on the the CSTMS repository for Dune (maintained by the USGS at https://svn1.hosted-projects.com/cmgsoft/dune/).

Wave-current bottom-boundary layer simulations over a flat, rough beds and over rippled beds have been performed for various wave-current angles. Modifications to Dune, including forcing for ripple simulations and a morphologic filtering algortim have been incorporated in the open-source code. Morphologic simulations of ripple evolution from both a flat bed and relict ripple field have been performed. Simulated ripple growth rate is consistent with laboratory observations. The new morphology module allows for the calculation of the wave energy dissipation as the bed evolves and allow comparison with simpler wave-current boundary layer models, suitable for use in ROMS. A parameterizaion of Dune results in terms of the Soulsby et al. (1993) formulation incorporated in ROMS by Blaas et al. (2007) is being prepared by Frank, Foster, and Sherwood (in prep).
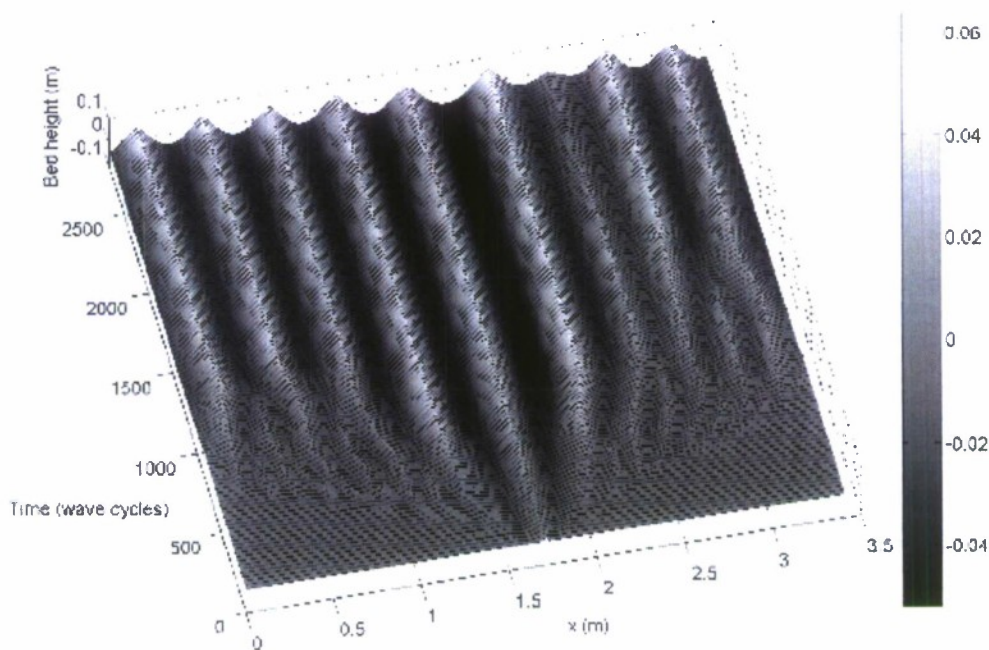

Figure 6. Evolution of an initially flat bed into linear ripples during a Dune simulation of wave-current bottom boundary layer flow.
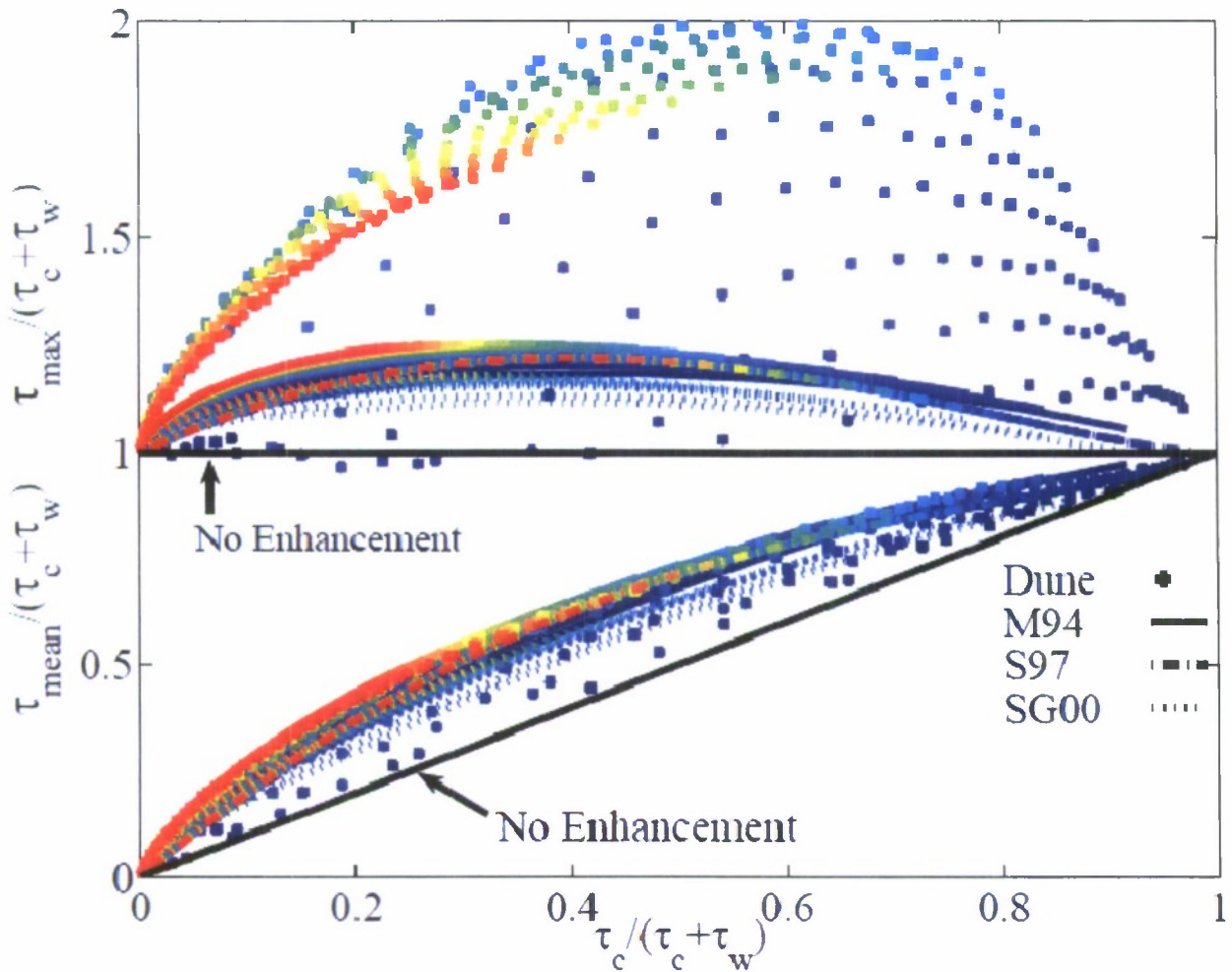
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Figure 7 Dune results plotted against other wave-current interaction models using the method of Soulsby et al. (1993, their Fig. 7), which emphasizes the non-linear enhancement of wave- and current- shear stresses when combined (from Frank, Foster and Sherwood, in prep).

Modeling wave-supported gravity flows

Hsu has developed a stand-alone model to investigate the vertical structure of wave-supported gravity flows such as those documented by Traykovski et al. (2007) on the California shelf and Po pro-delta. A high-resolution, one-dimensional model that resolves the phase of the forcing gravity waves is being used to test the hypothesized mechanisms controlling the vertical distribution of sediment within the wave boundary layer and the resulting cross-shelf transport. In addition to wave processes, the model includes the influence of flocculation, hindered settling, rheology, and turbulence-suppression by stratification. Figure 8 indicates that the model effectively captures the vertical structure of the suspended sediment distribution and the magnitude of the velocity (as well as can be characterized by available data). The analysis indicates that the intra-wave variability of stress is not crucial to the overall prediction of time-averaged concentration and velocities, because the settling timescale (i.e., wave boundary layer thickness divided by settling velocity, which is around 10 minutes) is in general much larger than the wave period (~10 sec). The key acheivement of this approach has been an improved parameterization (suitable for implementation in wave-averaged models like ROMS) for the thickness of fluid mud layers generated by waves.
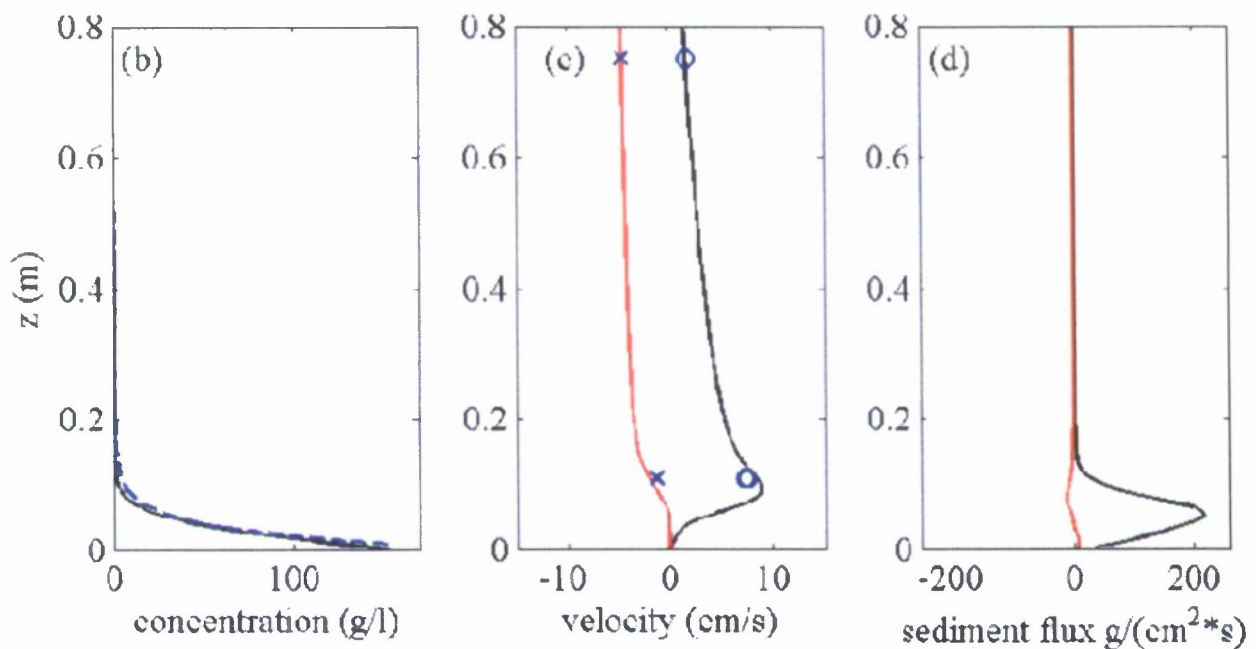
Figure 8. Model-data comparison of wave-supported gravity-driven mudflow for high concentration fluid mud event, from Hsu et al. (submitted). (b) Time-averaged mud concentration with solid curve represents model results and dashed curve represent measured data. (c) Modeled (black-solid curve) and measured (circles) time-averaged cross-shelf velocity profile and long-shelf velocity profile (red-solid: model results, crosses: measured data). (d) Model results on cross-shelf (black-solid) and long-shelf (red-solid) sediment fluxes.

High Resolution Numerical Modeling of Fine Sediment Transport and its Parameterization

Hsu is working on a robust and physically-based approach for modeling the transport of fine sediment in wave-current boundary layers across the entire spectrum of wave-current forcing and from dilute to dense sediment suspensions. He is using a phase-resolving, Reynolds-averaged Navier-Stokes (RANS) model as a test-bed to determine the appropriate scaling for the thickness of the wave-current boundary layer and the distribution of sediment under different forcing conditions. Based on these high-resolution runs, he is developing parameterizations that will be used in the phase-averaged CSTMS code. Hsu, Geyer, and Arango have developed a new gridding routine for ROMS-CSTMS that will provide high resolution of the wave boundary layer, as required for quantifying sediment transport under the influence of waves.

Parameterization of Sediment Entrainment Rate

Chang has been evaluating numerical model output from a large eddy resolving (LES) model of near-bottom flow to parameterize the sediment pickup function associated with small-scale convection. One of the difficulties has been quantifying the pickup rate from model output, and to do this, Chang has been evaluating the ratios of change rates of sediment concentrations near the bed against those slightly farther from the bed. The results are complicated and exhibit strong variation in time, space, and with changes in flow conditions and sediment characteristics, indicating that additional sets of LES model runs will be necessary.

Implementation of Cohesive and Mixed Sediment in ROMS

Sherwood and Ferré (USGS) implemented a cohesive-bed formulation for ROMS, with input from Sanford, Warner, and J. Paul Rinehimer (Virginia Institute of Marine Sciences). They incorporated the one-dimensional (vertical) model of Sanford (2007) model into the three-dimensional framework of ROMS. This is an example of the transition process from one-dimensional process models to operational elements in the CSTMS framework. Sherwood and Ferré modified the existing algorithms for tracking stratigraphy in ROMS to include profiles of sediment erodibility τ_{crit}. The model includes time-dependent consolidation and swelling algorithms, in which the profile of τ_{crit} relaxes back to an equilibrium profile after it has been disrupted by erosion or deposition. This implementation included mixed sediment, i.e., cohesive (mud) as well as non-cohesive (sand) fractions, which raised problem of specifying the transition between cohesive and non-cohesive behavior. As there is limited theoretical guidance for this transition, they applied an ad hoc gradation between non-cohesive and cohesive behavior, starting at fully cohesive behavior at 20% mud and fully non-cohesive behavior at 3% mud. The model also included an numerical implementation of solid-phase diffusive mixing for parameterizing biodiffusion at depth-dependent mixing rates that must be specified from data or a model of infaunal activity.

The model has been applied to a number of test cases, and the results are promising. Notably there are few algorithmic difficulties (e.g., numerical stability, logic errors, computational load, etc.), and the most serious issues are related to specification of rates and initial conditions (which are challenging problems). The tests to date include a modulated tidal flow, a sequence of wave events, and an idealized simulation of the western Adriatic shelf in an attempt to reproduce the observed sand-mud transition. The result of the latter simulation indeed produces a migration of the sand-mud transition to the 10-20 m isobath, consistent with observations. Although these tests are preliminary, they indicate an important step toward a prognostic representation of a cohesive and/or mixed sediment bed in the CSTMS implementation of ROMS.

Total Load Sediment-Transport Formulation

A prediction formula for the total-load transport of sand under non-breaking waves plus a current, named ParaSedFlux, was developed by the HR Walingford team (Soulsby, 2009) given as a set of algebraic equations, and was summarised in an appendix as an algorithm suitable for programming into a module for use in coastal numerical models. The predictor is based on a parameterisation of a set of 858 runs of the sediment transport prediction model SedFlux2007 which was developed over a number of years at HR Wallingford. The processes modelled by SedFlux2007 are described, and tests against field and laboratory data, made as part of previous European Union research projects, are presented to quantify the capabilities of the model. The report describes the method of parameterising the model, and the degree of fit of ParaSedFlux to the full model has been quantified. ParaSedFlux is computationally efficient, and the algorithm has been supplied with limits of validity of the inputs for use within the community sediment-transport models.

3. CSTMS Tools, Documentation, and Community Involvement

Technical support for the community model development was supported by the Rutgers team. Arango and Robertson maintained the systems that served the code repository, Wiki, and discussion groups. Many PIs contributed to on-line documentation (https://www.myroms.org/wiki/) and discussions

(https://www.myroms.org/forum/). A separate forum initially developed by the USGS and Rutgers at http://www.cstms.org has summaries of model applications.

Mississippi State investigator Bhate, with guidance from Signell, developed an advanced regression package for ROMS. This package allows ROMS to run through a suite of simulations that test compiling, linking, configuration and monitors changes in results. In a complex modeling environment, a regression package helps developers find bugs before sending out for user testing, reducing user frustration when a new version arrives and the old configurations no longer work. Because of the modular extensible environment, the package can be configured easily for other tasks, and new users have found it a convenient environment for setting up and running new CSTMS simulations.

Bhate and Signell also developed a netCDF Java toolbox for Matlab (njTBX), a suite of routines that facilitates interaction with model output in standard formats. This toolbox has been released and updated and is available online at http://sourceforge.net/apps/trac/njtbx.

ROMS User's Workshops were held at the University of California, Los Angeles October 2007; at Jean Kuntzmann Laboratory, Saint Martin d'Heres Campus, Grenoble, France, October, 2008; and at the Sydney Institute of Marine Science in Sydney, Australia, March 2009. The UCLA meeting coincided with a CSTMS meeting, and the Sydney workshop included two half-day tutorials on ROMS and CSTMS.

4. Applications

Teignmouth

The HR Wallingford team developed a regional test case for hydrodynamics, sediment transport and morphological change at Teignmouth (UK) as part of the COAST 3D programme. Three test cases have been developed for ROMS, including two tidally dominated cases and one case with large wave forcing of nearshore circulation. Everything is in place with information available for the specification of boundary conditions. Initial work has been completed on developing a ROMS model grid for the Teignmouth inlet but getting the model to run in the complex macrotidal environment took longer than expected. However, the model has been successfully run with tidal and fluvial forcing (Figure 9), and the USGS and HR Wallingford plan to complete the Teignmouth testing in early 2010.
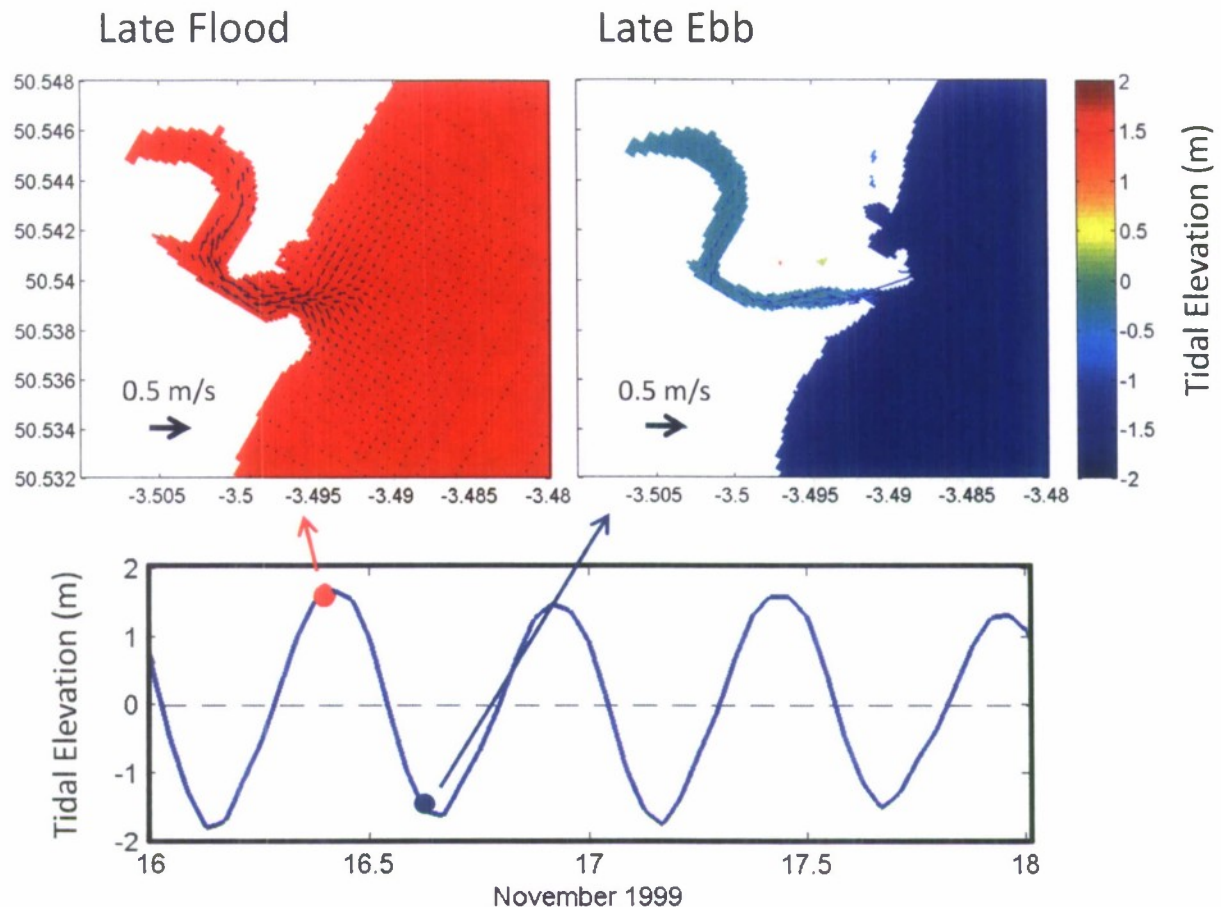
Figure 9. Simulation of tidal flow in the Teignmouth Estuary with wetting and drying.

Hudson River Estuary

Warner, Geyer, and Arango developed an application of ROMS/CSTMS in the Hudson River estuary that takes advantage of the composite grid capability developed in this project. As a proof-of-concept of the segmented grid approach, they investigated salt transport and the residence time of a passive tracer. They are in the process of applying the same domain to the sediment transport problem.

MVCO

Ganju and Sherwood (USGS) developed a nested, coupled application for the region near the Martha's Vineyard Coastal Observatory, in conjunction with the ONR Ripples DRI project and the OASIS project. This application uses the Ripple Predictor (Mark II) developed by Whitehouse and Soulsby (2005) as part of an earlier ONR Mine Burial project.

Southern California Bight

The UCLA group has successfully updated the triple nested regional configuration for the Palos Verdes Shelf encompassing Santa Monica and San Pedro Bays, CA, with a 200-m spatial resolution for non-cohesive sediment transport simulation embedded in the intermediate Southern California Bight domain with 1 km resolution, fed by the outermost U.S. West Coast domain with 5-km

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resolution (used to be 20 km; Dong et al., 2009). Compatible double nested atmospheric modeling with WRF and wind-sea/swell prediction with SWAN have also been accomplished. The extensive upwelling event occurred in March 2002 is better reproduced with evident appearance of submesoscale spiral eddies all over the inner-most domain. The high-resolution inner domain produces shoreline eddies associated with passage of a frontal structure right at the shoreline to form filament patterns in SSS and then to roll up into cohesive submesoscale eddies. These features indicate the critical importance of multiple nesting to provide realistic simulations of submesoscale structure in coastal environments.

COAWST

Warner, working with USGS funding for the Coastal Carolinas Change Processes project, has developed a mutliply nested, coupled application for weather, circulation, waves, sediment-transport and morphologic change (coupled ocean, atmosphere, wave, and sediment transport model; COAWST) off North and South Carolina, focussing on processes that maintain cape shoals. This project is distinct from CSTMS, but benefits from CSTMS development of ROMS and incorporates collaborators including Ruoying He (N. Carolina State), Kevin Haas (Georgia Tech), and George Voulgaris (Univ. of South Carolina). The USGS intends to maintain and improve this modeling system and incorporate advances into the ROMS code.

IMPACT/APPLICATIONS

CSTMS provides a starting point for a wide range of numerical investigations. It is a tool for scientists who are interested in coastal and estuarine processes and need the numerical context of a high-quality physical oceanographic model. The physical oceanographic model ROMS and the non-cohesive sediment-transport algorithms in the CSTMS associated with ROMS are sufficiently mature for a wide range of applications, and are being actively used by researchers worldwide.

TRANSITIONS

Researchers not funded by the NOPP project are presently using the model in the Adriatic Sea, Chesapeake Bay, Louisiana, and other locations.

RELATED PROJECTS

Testing and application of the CSTMS benefited from field measurements obtained during ONR STRATAFORM., EuroSTRATAFORM, the Mine Burial Experiment, CBLAST, the Ripples DRI, SandyDuck, NCEX, the Mud Flats DRI, and the Coherent Structures MURI. Data from USGS projects in Massachusetts Bay, Vineyard Sound, South Carolina and Palos Verdes have been used, as have data from the NSF and Hudson River Foundation studies in the Hudson River. The model was informed by process studies conducted as part of Nearshore NOPP project, OASIS, the Ripples DRI, CBLAST, Hudson River studies, and various USGS and NRL projects. This project provides a template and model modules for the NSF CSDMS project.

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